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Evaluation of Forest Fires with GIS

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Introduction

❖ Whether caused by natural factors or human activity, wildfires can have devastating impact on environment and they are regarded as one of the most significant factors leading to land degradation.

❖ A precise evaluation of wildfire events and decisions on solution methods can only be satisfactorily made when a fire risk zone map is available.

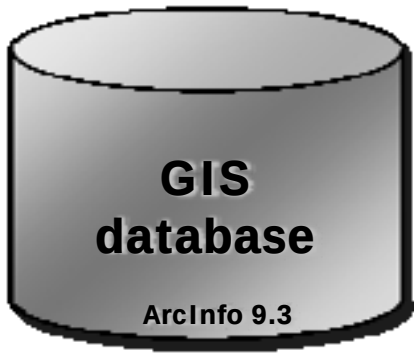
❖ Since wildfires depend on spatial parameters, effective use of *Remote Sensing* (RS) and *Geographic Information Systems* (GIS) can help to prepare wildfire risk maps based on certain criteria and parameters and to develop proper solution methods.

Scope of the study

- To generate a wildfire risk map by combining human factor, vegetation cover and topographic factors by utilizing *"RS & GIS"* technologies.
- To illustrate how to convert the original wildfire data into areal units defined by a raster grid by *"Kernel Density Estimation"* .
- Hot spot analysis of historic fire data.

Data

- 1/25.000 topographic maps
- 3 arcsec (90 m) SRTM data
- Color composite SPOT satellite image
- Digital stand map
- Historic fire data between 1999 – 2009



Study area

❖ *"Mumcular Forest Sub-District"* of Muğla city in Turkey, which has been severely suffering from forest fires during the last decade, was chosen as study area:

37⁰ 06' 24.84" N 27⁰ 39' 55.79" E

Mumcular Forest Sub-district, Muğla

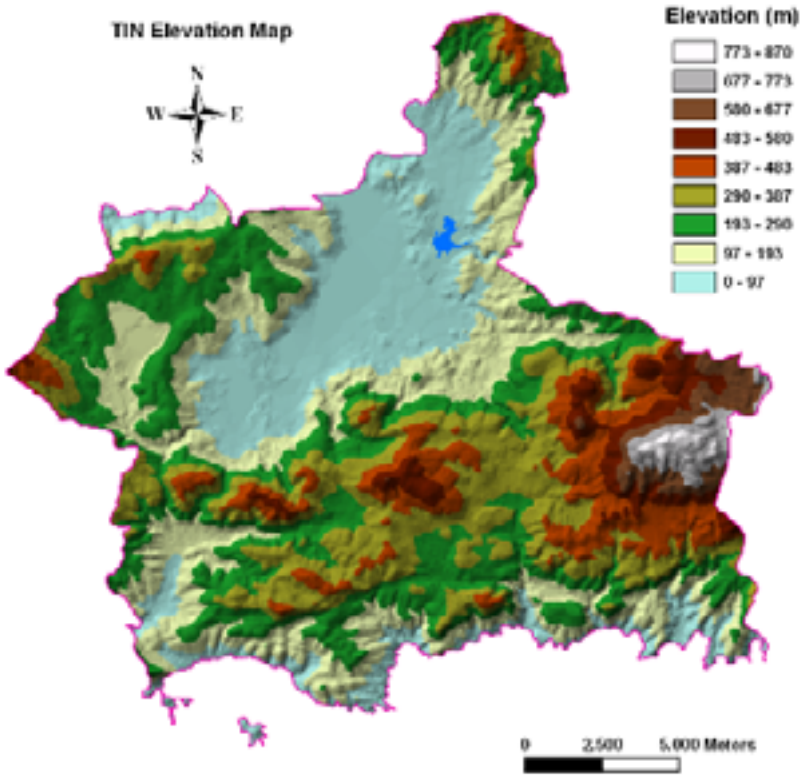
Total area:32.172 ha

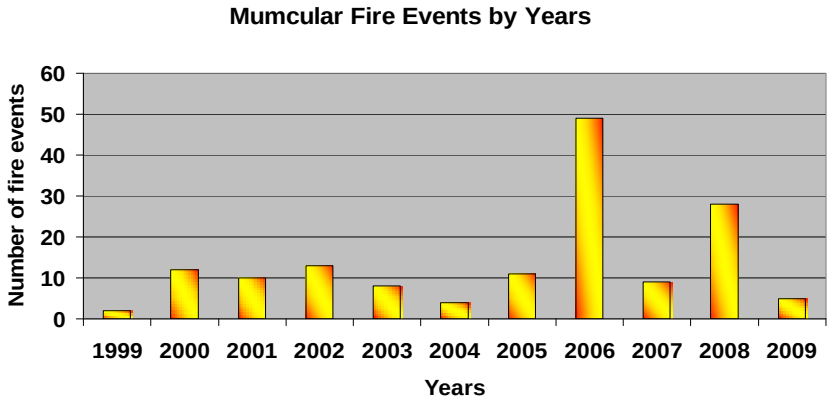
Forested :21.416 ha

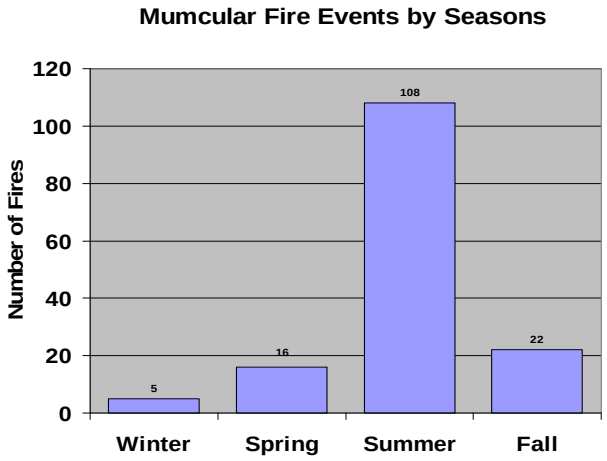
1ha = 0,01 km²

Study area

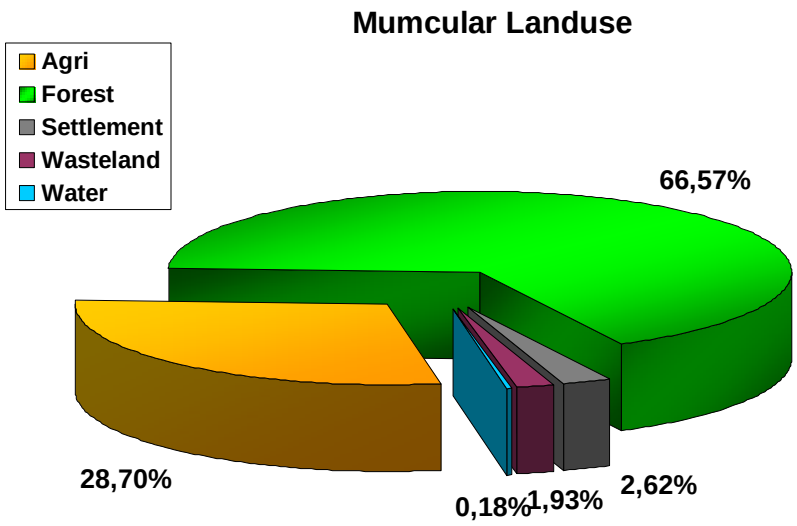
- Total number of wildfire events between 1999 – 2009: **151**
- Dominant tree specie: *"Pinus brutia"* (also known as red pine)

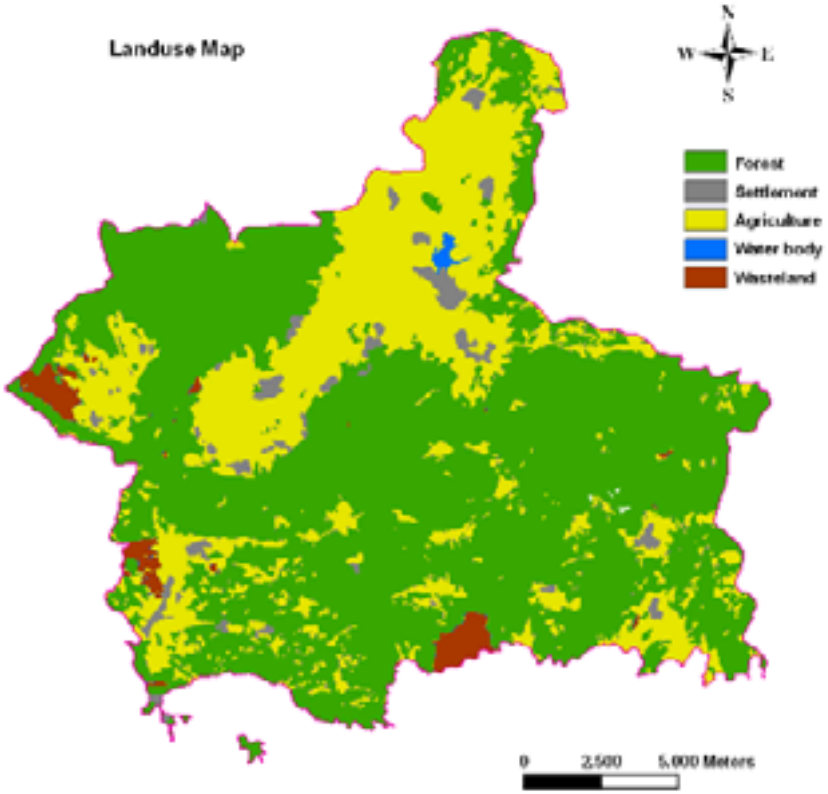






Landuse classification

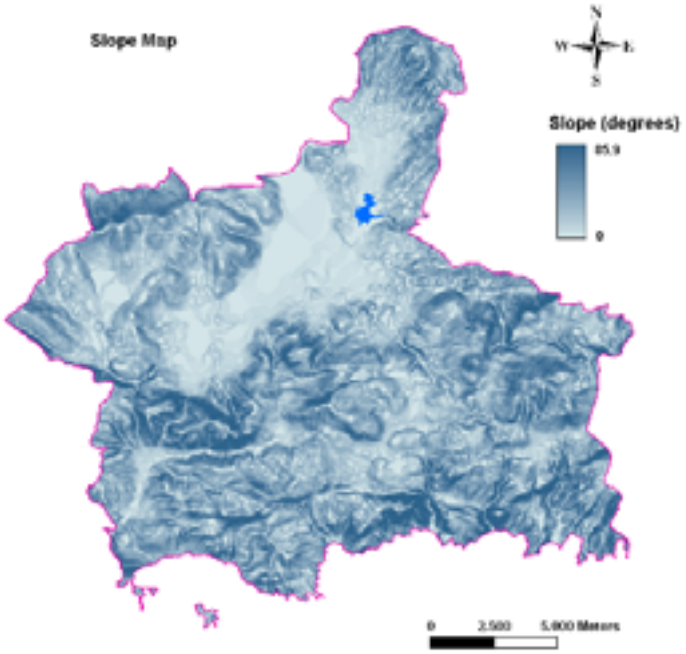


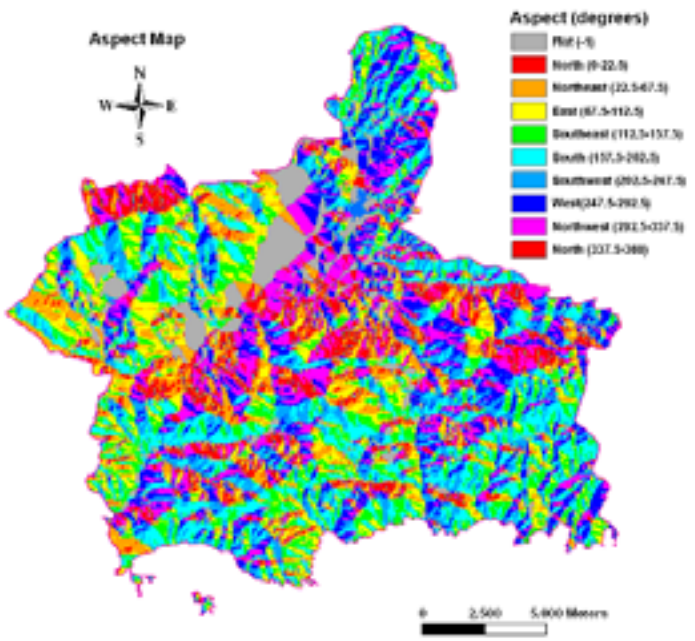


Topographic factors

❖ ***Slope & Aspect:*** Fires spread faster at locations with steeper slopes. Moreover, southern facing aspects are exposed to more solar radiation than northern ones; therefore, it has also to be taken into account.

3 arcsec SRTM data → Slope & Aspect → Slope & Aspect risk rating maps





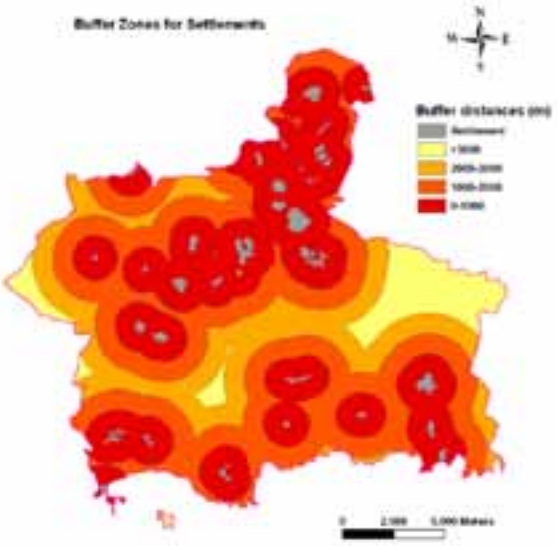
Anthropogenic factors

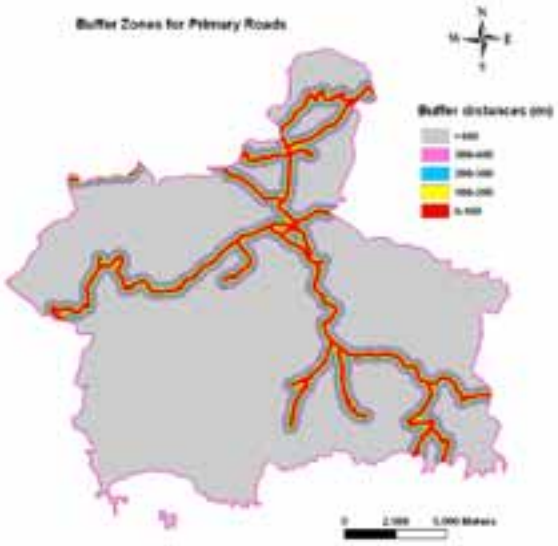
❖ ***Settlements, Roads & Straw Fires:*** Movements and activities of humans always increase the potential risk of fire. Another anthropogenic factor that has to be considered is the fact of straw fires.

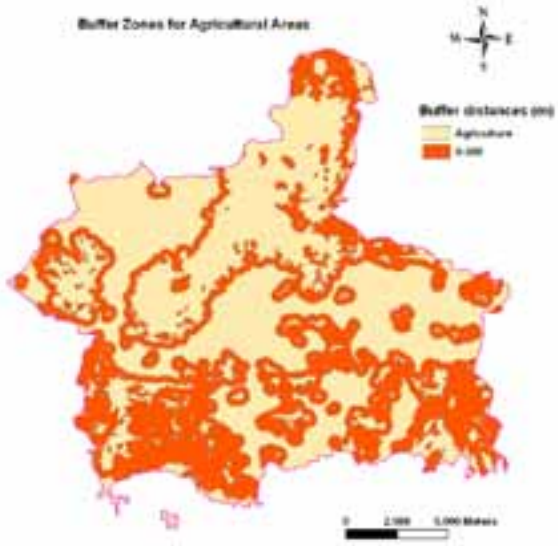
Topographic maps —by digitizing→ Primary & Secondary roads

Digital stand map → Settlements & Agricultural areas

"Buffer Zones" with corresponding risk ratings





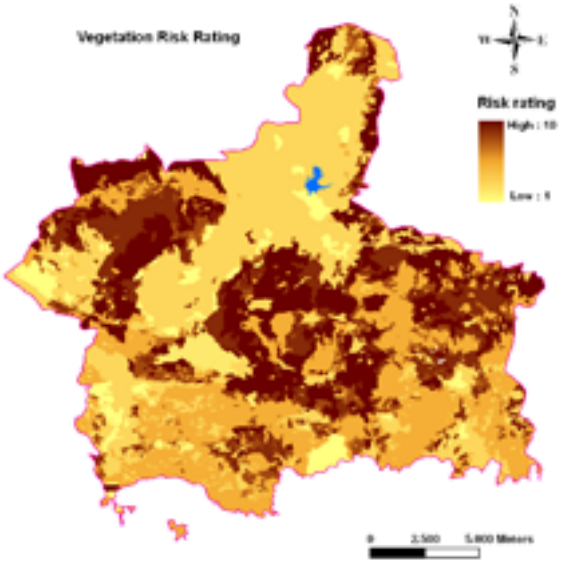


Vegetation factor

❖ ***Vegetation cover:*** Most significant factor contributing to potential fire risk. *"Pinus brutia"* constitutes about 97 % of the forested areas (20.685 ha). Moreover, 43 % of the forested land has canopy density > between 41 %.

Digital stand map
&
Classified satellite image

→ Vegetation risk rating map

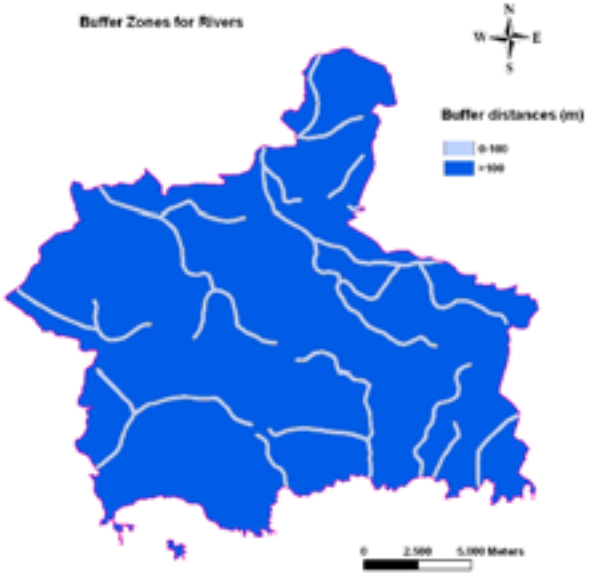


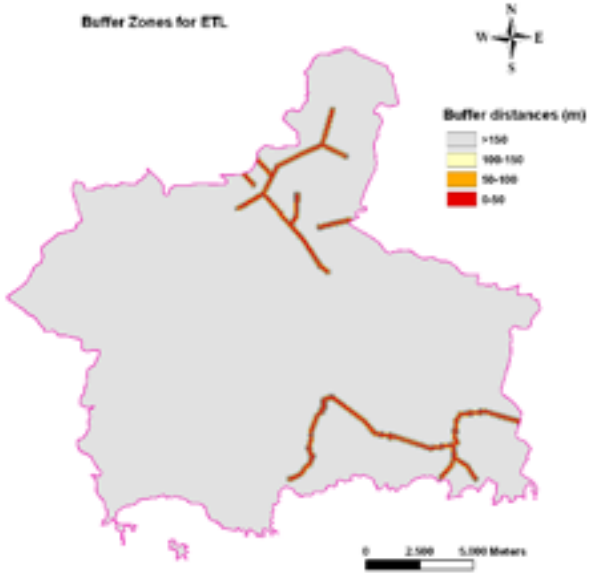
"Risk ratings" categorized into 8 groups with respect to type, growth stage and canopy density

Other factors

❖ ***Rivers & Electric Transmission Lines (ETL):*** Since level of humidity around water resources is higher, these areas have less potential fire risk. A breakdown on energy transmission lines may easily ignite a fire in risky areas.

Topographic maps —by digitizing→ Perennial rivers & ETL } **"Buffer Zones"** with corresponding risk ratings

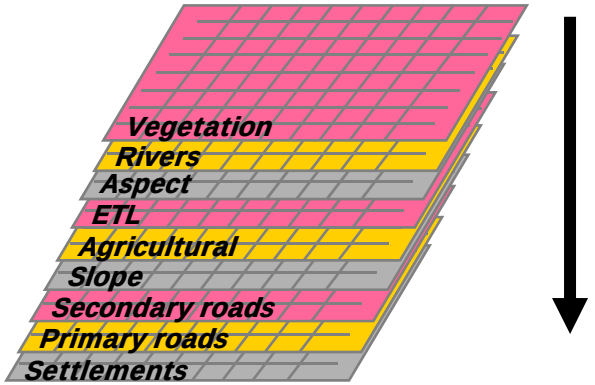




Calculation of wildfire risk index value

❖ ***WRIV:*** By overlaying nine raster sets in total, each of which has associated risk ratings and different weight factor.

$$WRIV = 20V_{i=1-10} + 12St_{j=1-7} + 10(Pr_{k=1-8} + Sr_{l=1-8}) + 9Sl_{m=2-10} + 7A_{n=1-3} + 6E_{o=1-5} + 3As_{p=1-4} + R_{r=1-3}$$



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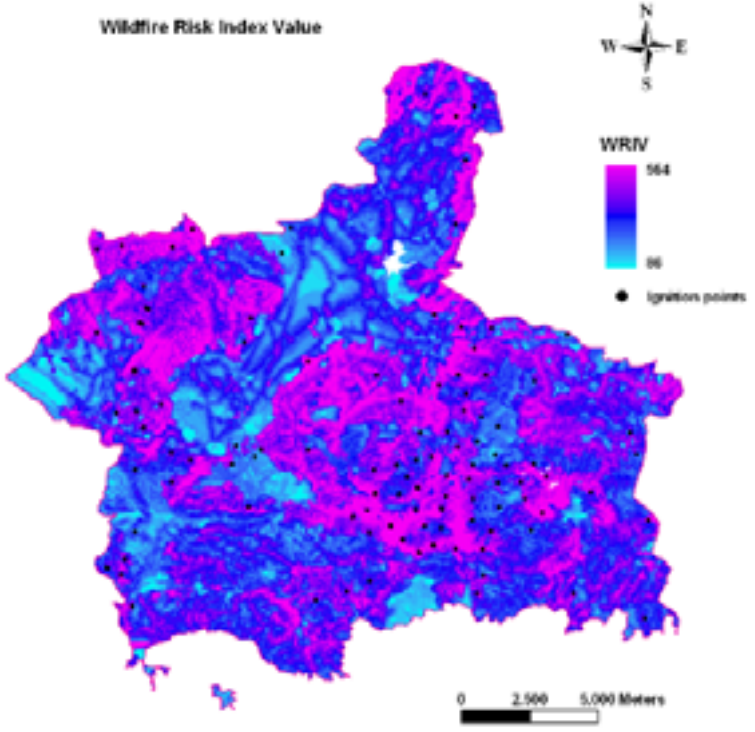
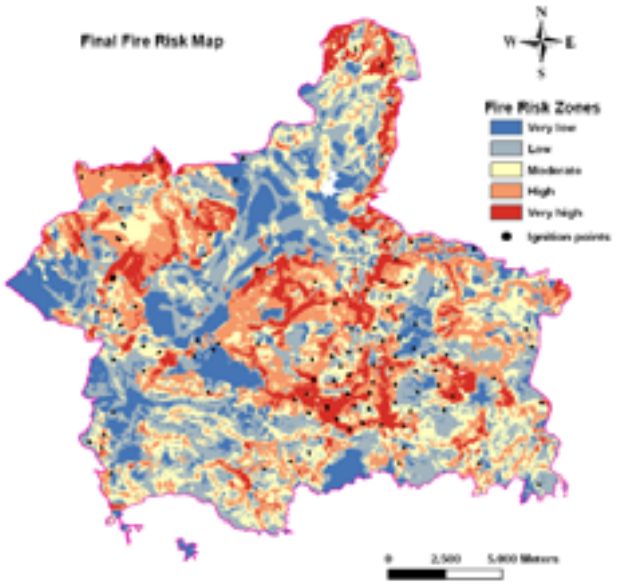
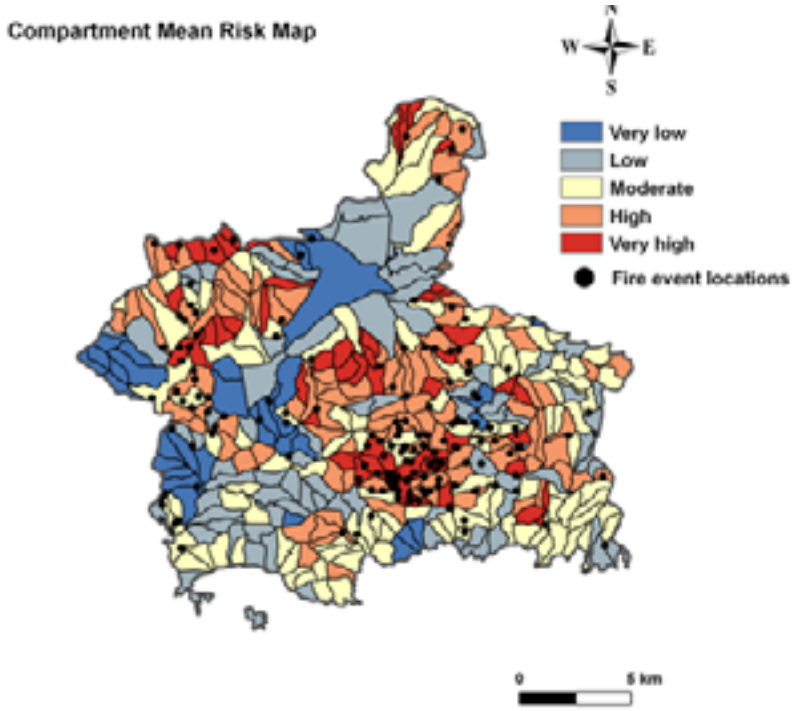


V: Vegetation
St: Settlements
Pr: Primary roads
Sr: Secondary roads
Sl: Slope
A: Agricultural
E: ETL
As: Aspect
R: Rivers

Final risk maps

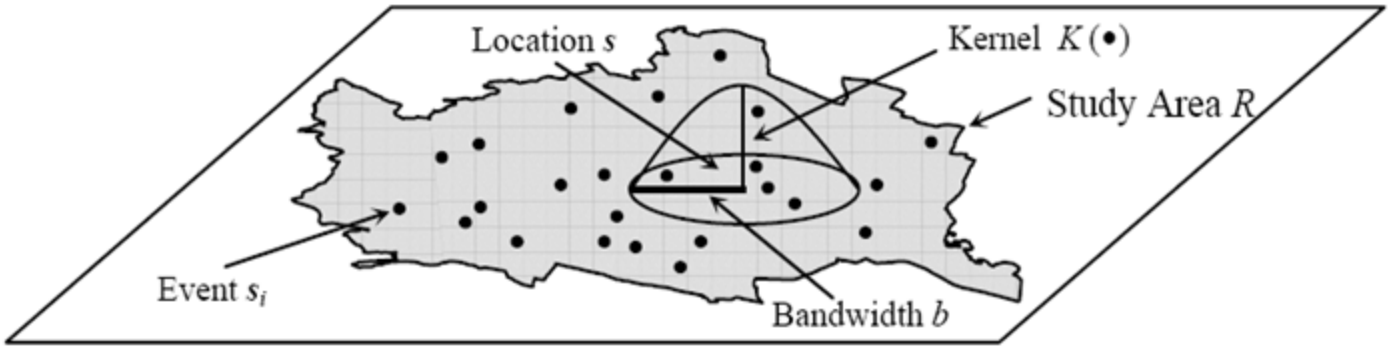
❖ The obtained *WRIV* map is categorized into 5 groups by *"Jenks Natural Breaks"* , and compartment mean risk index map is obtained (total number of compartments in the stand map: **373**).





Kernel density estimation (KDE)

❖ When dealing with fire risk, conversion of the dependent variable (historic fire occurrence) into a continuous surface is required in order to statistically compare and analyze it with human factors, environmental parameters and census statistics.



$$\hat{f}(s,b) = n^{-1}b^{-2}\sum_{i=1}^{n} K\{(s - S_i)/b\}$$

n: total number of point observations

b: smoothing parameter (i.e. bandwidth)

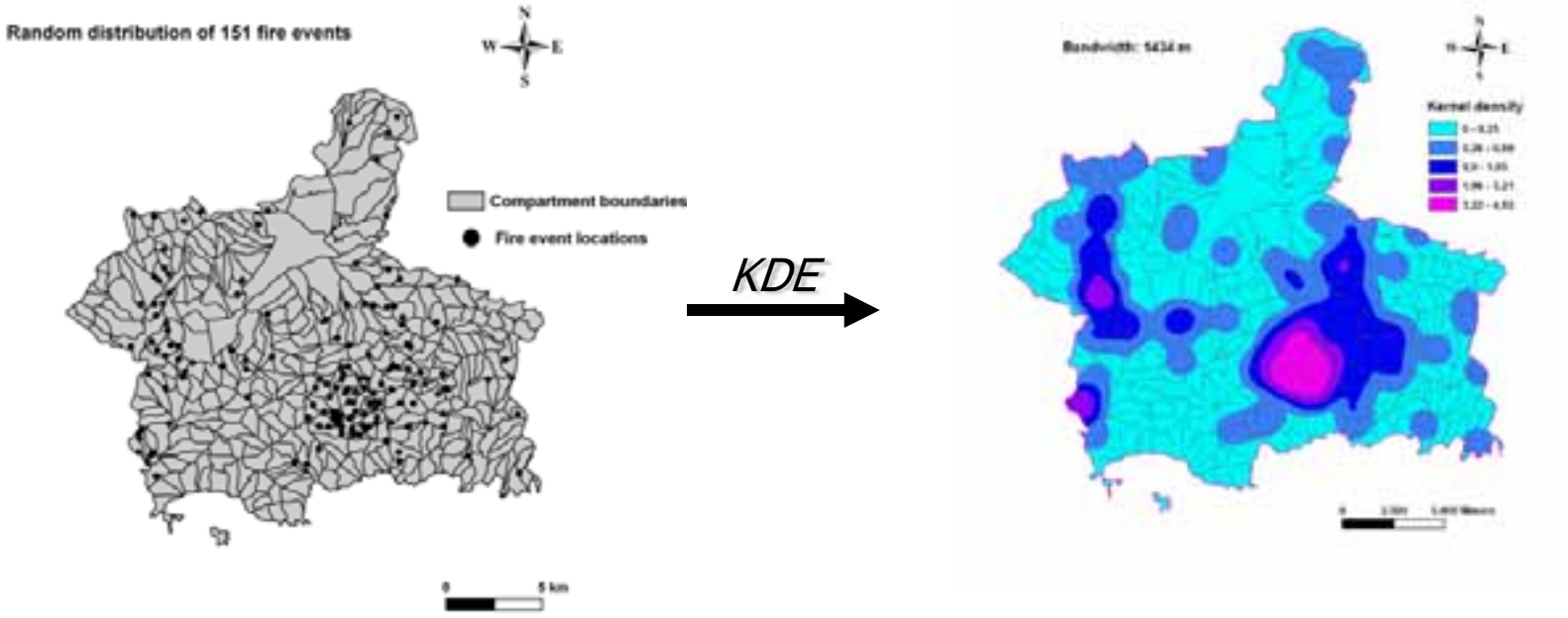
s: vector of coordinates denoting the location where the function is being estimated

Si : vector of coordinates representing each observation

K: symmetrical bivariate kernel density function

Kernel density estimation (KDE)

❖ Exact *x* and *y* coordinates of fire events are not available. Instead, the compartment numbers of these events are known.



$$RDmean = \frac{1}{2}\sqrt{\frac{A}{N}}$$

Bandwidth: 1434 m

A: total area

N: total number of wildfire events

(*Note:* Double of *RDmean* is taken as bandwidth.)

Hot spot analysis

- Hot spot calculates the Getis-Ord Gi* statistic for each feature in a dataset. The resultant Z score gives where features with either high or low values cluster spatially.
- A feature with a high value is interesting, but may not be a statistically significant hot spot. To be a statistically significant hot spot, a feature should have a high value and be surrounded by other features with high values as well.
- For statistically significant positive Z scores, the larger the Z score is, the more intense is the clustering of high values (hot spot). For statistically significant negative Z scores, the smaller the Z score is, the more intense the clustering of low values is.

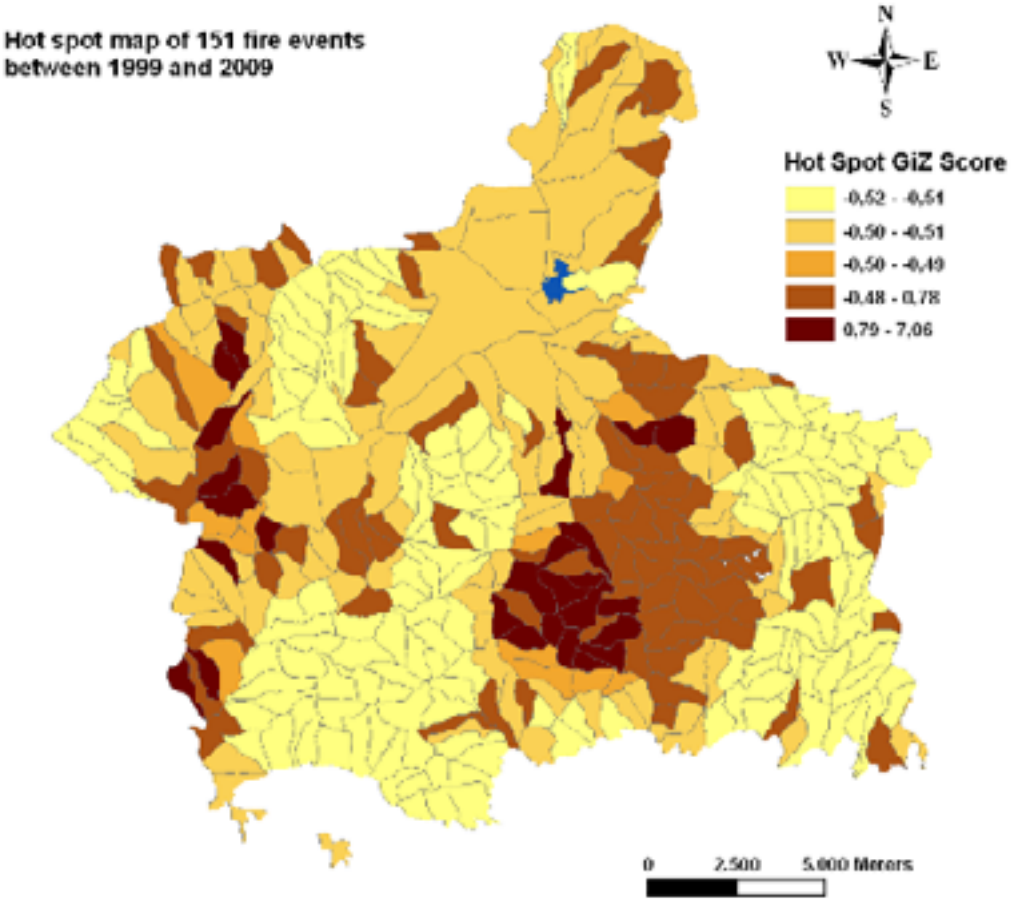
$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{X}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}}$$

where x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weight between feature i and j, n is equal to total number of features and:

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n}$$

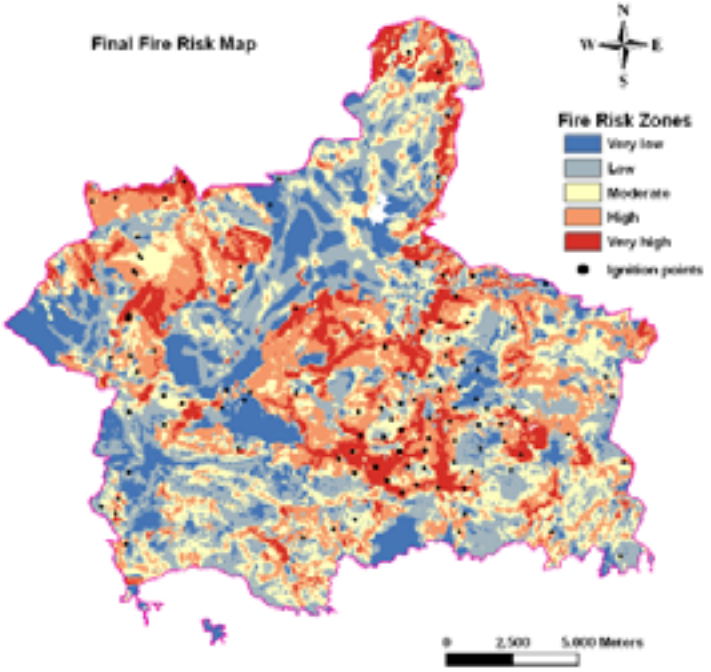
$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \left(\bar{X}\right)^2}$$

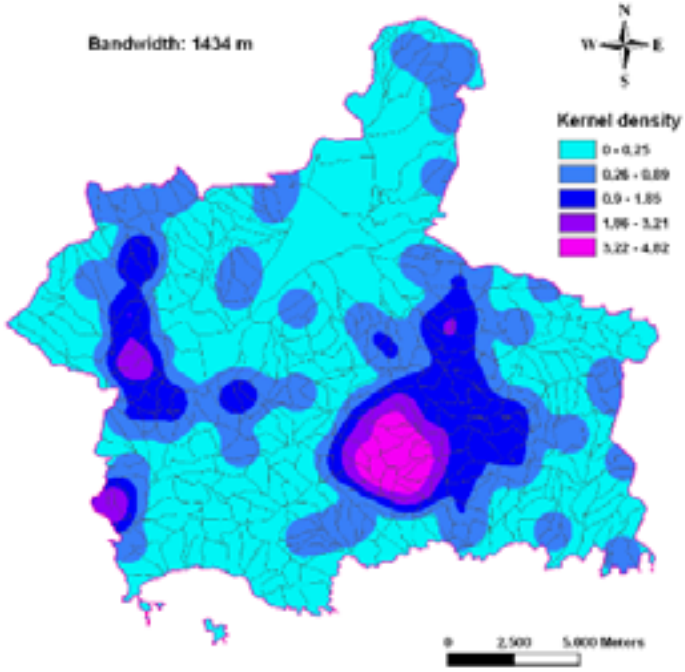
Hot spot analysis



Results

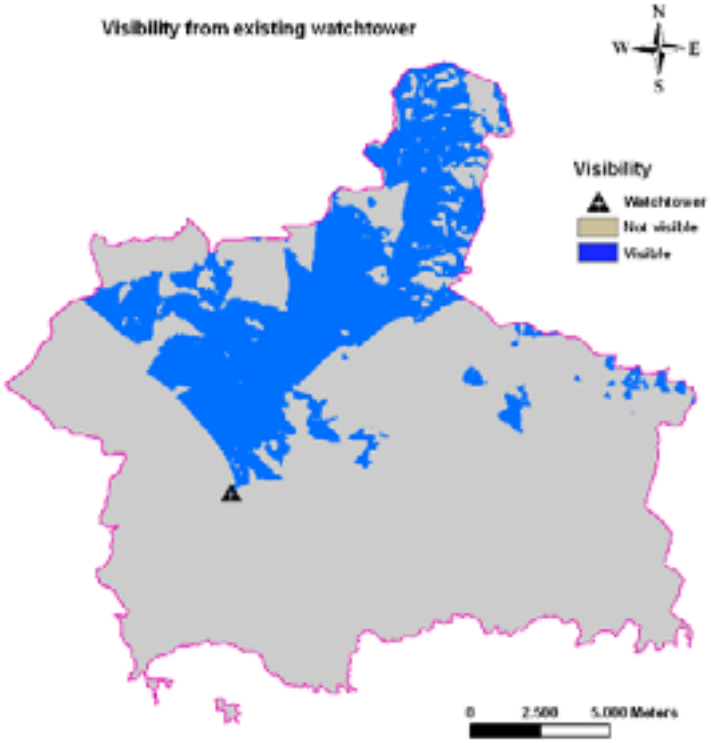
- Visual comparison of final fire risk map and kernel density map

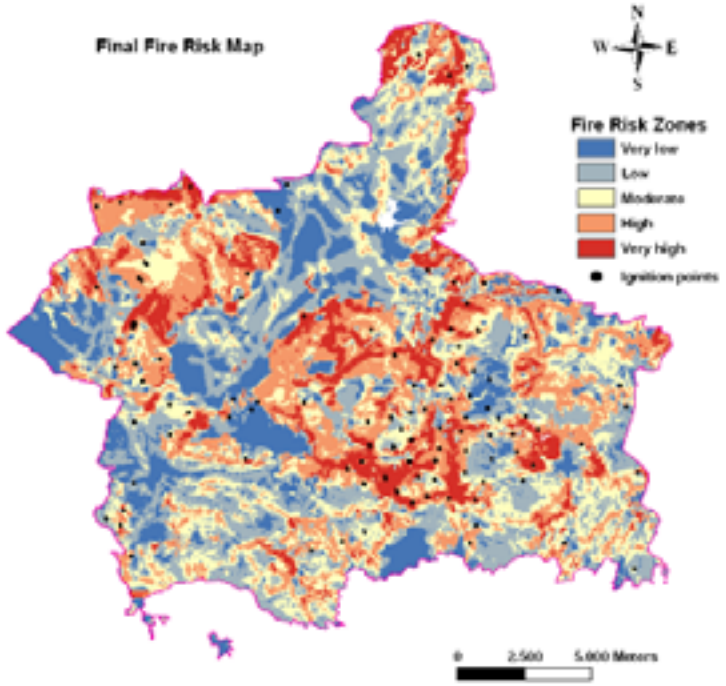




Results

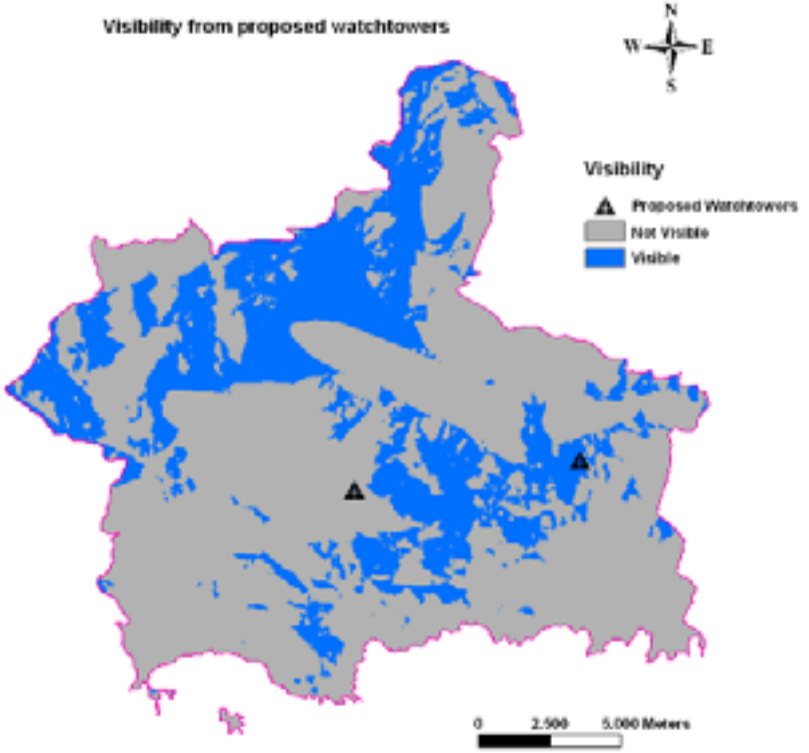
- Visibility analysis

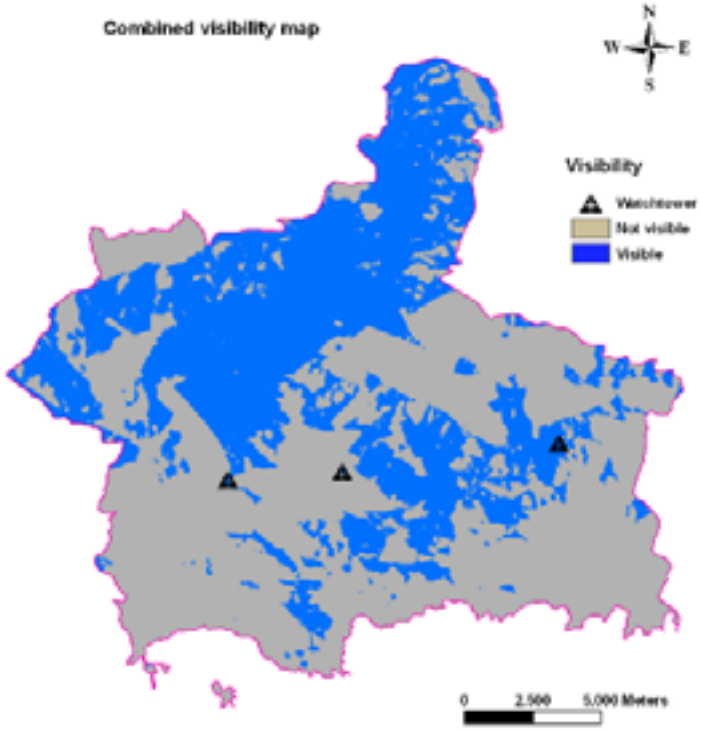




Results

- Visibility analysis





Results

Concluding Remarks

- It was a noticeable fact that the produced general kernel density map was in close agreement with the final risk index map, and this significant finding was also supported with the obtained hot spot maps.
- According to historic fire data, 97% of the fire incidences between 1999 and 2009 in the study area were caused by human factor. Therefore, public awareness program should immediately be implemented at district level to decrease the human-caused forest fire rate.
- There is only one fire watch tower in Mumcular Forest Sub-district, located at Kale Tepe, and when analyzed by viewshed tool in ArcGIS, it has very limited visibility condition taking account of the fact that the fire events are concentrated more towards a bit south-east direction from the central part. Therefore, new watch towers should be installed at proposed locations in the study area.
- As proven in this study, a fire risk map produced by an effective integration of RS and GIS technologies and investigation of spatial distribution of historic fire data by kernel density and hot spot analysis are surely helpful for forest fire managers to take necessary measures against forest fires at more risky areas and to prepare rehabilitation plans for more efficient road network, communication and transport systems.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Thanks for your attention!